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# An Analysis into Relationships that may Exist between Population and the Reported Number of Tornadoes in the Continental United States

Adam Bundick Thomas

AN ANALYSIS INTO RELATIONSHIPS THAT MAY EXIST BETWEEN

POPULATION AND THE REPORTED NUMBER OF TORNADOES

IN THE CONTINENTAL UNITED STATES

By

Adam Bundick Thomas

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By

Adam Bundick Thomas

Approved:

Michael E. Brown
Associate Professor of Geosciences
(Director of Thesis)

Jamie L. Dyer
Assistant Professor of Geosciences
(Committee Member)

John C. Rodgers, III
Associate Professor of Geosciences
(Committee Member)

Paul G. Dixon
Assistant Professor of Geosciences
(Committee Member)

Christopher P. Dewey
Associate Professor of Geosciences
Graduate Coordinator of the
Department of Geosciences

Darrel Schmitz
Professor of Geosciences
Professor and Head,
Department of Geosciences

Gary Myers
Professor and Interim Dean of the
College of Arts and Sciences

Name: Adam Bundick Thomas

Date of Degree: May 3, 2008

Institution: Mississippi State University

Major Field: Geosciences

Major Professor: Michael E. Brown

Title of Study: AN ANALYSIS INTO RELATIONSHIPS THAT MAY EXIST BETWEEN POPULATION AND THE REPORTED NUMBER OF TORNADOES IN THE CONTINENTAL UNITED STATES

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Candidate for Degree of Masters of Science

Many studies have suggested that the tornado database is biased by the concentration of human observers. Some studies have shown a possible 66% decrease in tornado reporting can be directly attributed to population density. This study examines whether or not such biases exist throughout the United States. Population data are compared to the historical tornado database in order to better understand the relationship(s) between each variable. Various statistical and spatial techniques are implemented in order to better identify relationships. As expected, weak (F0-F1) tornadoes show a correlation to both population patterns and travel routes. However, not all regions of the United States share the same relationships during the study period. Therefore, any meaningful adjustment to the tornado climatology cannot be made because of the variation in both spatial and temporal changes.

## DEDICATION

I would like to dedicate this work to my parents, Benjy and Phyllis Thomas. I will always be grateful for your love and support.

# ACKNOWLEDGMENTS

First and foremost, I would like to thank my thesis advisor Dr. Mike Brown for his support and guidance throughout this project. I will always be grateful for the time and patience that he gave me throughout this work. I would also like to thank my thesis committee Dr. Jamie Dyer, Dr. Grady Dixon, and Dr. John Rodgers for all of their time and assistance throughout the course of this research.

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# CHAPTER I

# INTRODUCTION

The study of tornadoes is a critical practice in the meteorological community, which can ultimately save both human life and property. Often, tornado research utilizes the frequency and geographic distribution of past tornadoes (Beal 2007, Jackson 2006, and Rose et al. 2003). As has been noted in some studies, (Doswell and Burgess 1988, Forbes and Wakimoto, 1983) there are many factors such as inconsistent reporting standards, unreported tornadoes, and reports of fictitious tornadoes that can cause inaccuracies in the historical tornado record. These inaccuracies will then cause a misrepresentation of the spatial distribution of tornadoes and a false understanding of where tornadoes are most likely to strike in a given region. In addition, research that attempts to understand the atmospheric conditions at the time of and just preceding tornado events will be biased toward regions in which tornadoes are recorded. Biases related to the human observer such as population density, location, and level of education may skew the understanding of tornadoes and the physical processes associated with their formation.

The Severe Storms Prediction Center has developed a comprehensive record of all reported tornadoes in the continental United States since 1950. The process of reporting these tornadoes is conducted primarily by members of the public. To date, no standardized reporting procedures exist for severe storm events. As a result, there is likely a mis-representation of tornado events in many regions of the country. Factors such as time of day, distance from major road networks, population density, the presence or absence of spotter networks, and the education level of the public can impact the proper reporting of a tornado (Kelly et al. 1985). Since many reports depend upon individual perceptions of "severe", there are no linear corrections that can be applied to the database.

A precursory analysis of the historical tornado database shows that there has been an increase in the number of reported tornadoes throughout the SPC tornado record (Figure 1.1). Within the lower 48 states, there were 4,791 reported tornadoes during the ten-year span of the 1950's. By comparison, there were nearly three times as many reported tornadoes in the 1990's with 12,134. The steady increase in reported tornadoes may be explained by factors such as better meteorological tools, population growth, and a better-educated public.

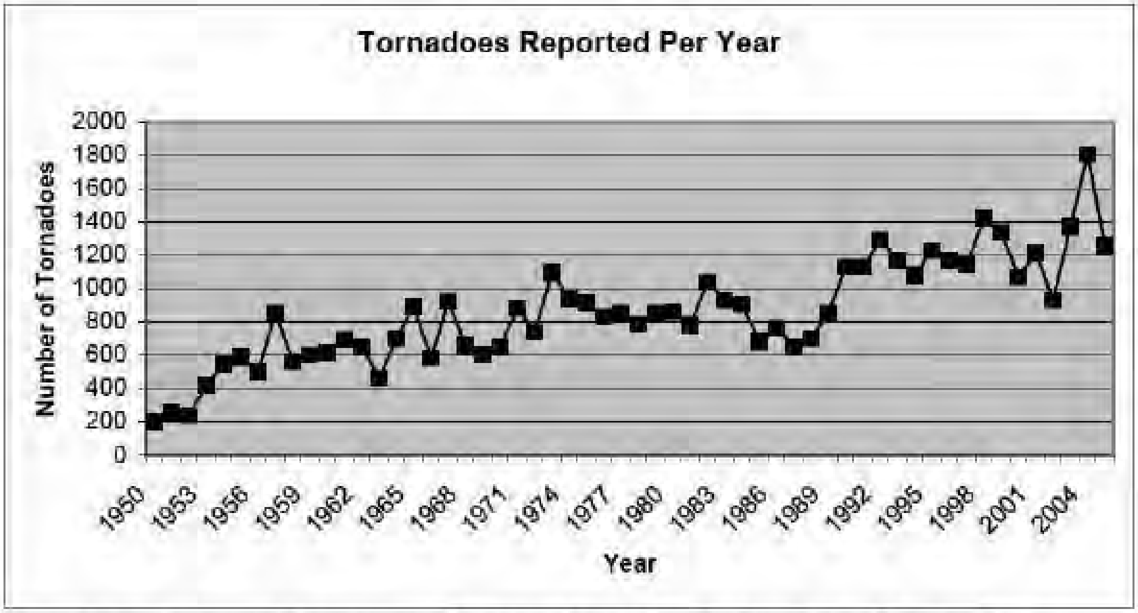


Figure 1.1. The annual frequency of reported tornadoes in the United States from 1950-2005.

As a result of advances in analytical meteorological tools such as the Weather Surveillance Radar (Doppler) (WSR–88D), meteorologists are now able to detect signatures related to tornadoes with greater reliability and confidence. Although improved meteorological techniques have enabled more potential tornadoes to be detected in recent years, it is probable that many tornadoes still remain undetected. The problem of a tornado occurring in a location and not being reported due to a lack of observation or damage still exists (Kelly et al. 1985). Tornadoes that are not reported in a specific region for any reason can distort the spatial distribution of tornadoes that occur in that geographical location. If the lack of reporting was uniform across the country, adjustments to the tornado database could be made. However, as Kelly et al. (1985) point out, the relationship between reporting discrepancies and the population is not linear and is instead based upon variables such as education, distance to the reporting site, and the perception of the severity of storms. The purpose of this study is to determine if a measurable population-tornado relationship can be detected in the continental United States (CONUS) and various regions within the CONUS. If identified, this bias may be used to adjust the spatial distribution (a bias correction) of the tornado climatology for the Continental United States.

## OBJECTIVES AND HYPOTHESIS

The objectives of this study are:

1.) To identify regions in the continental U.S. that have a likely under representation of the total number of tornadoes that have actually occurred;

2.) To establish an understanding of the magnitude of possible relationships between population and tornado reporting in areas that have been identified as having a likely under representation of the total number of tornadoes that have actually occurred.

The following hypotheses will be tested in this study:

1.) There is a greater reporting frequency of weak F0-F1 tornadoes in areas of high population density than in areas of neighboring low population density.

2.) The population bias is not as strong in the most recent years of the tornado database.

## CHAPTER II

## LITERATURE REVIEW

Relatively little research has been conducted on the seemingly large problem of observation bias in the tornado record. Schaefer and Galway (1982) suggest that only two of every three tornadoes are observed in the U.S. Studies conducted at a regional level show an even greater under representation. For example, a study conducted on Iowa tornadoes indicated that only 33% of tornadoes that actually occurred were reported (Eshelman and Stanford, 1977). Another study on Michigan tornadoes found that only 33% of tornadoes that occur in rural areas of the state are reported (Snider, 1977). In a study conducted in the Great Plains, Ray et al. (2003) found that the actual number of tornadoes was 60% greater than the total reported number. Although recent improvements in the reporting of tornadoes may have improved the overall reporting statistics of the tornado database, these studies show that an underestimate, in some cases a dramatic underestimation, in the number of total tornadoes exist in the database.

Anderson et al. (2007) suggest that lakes, trees, hills, and absence of roads are just some of the many variables that can hinder human detection of tornadoes. However, they also suggest that population density is the most practical explanatory variable because it is easily assessable from census bureaus, it is relatively easy to use in statistical models, and it has a direct relationship to other landscape variables. Newark (1983) advanced the idea of the importance of population density even further by estimating that 1.5 persons $km^{-2}$ is needed in order for most tornadoes to be observed. In a later study, King (1997) estimated that the threshold population density is approximately 6 persons $km^{-2}$.

Anderson et al (2007) studied the population centers and surrounding counties of Atlanta, GA; Champaign, IL; Des Moines IA; Oklahoma City, OK; Omaha, NE; and Tulsa, OK. When Oklahoma City and Tulsa were analyzed, it was found that the probability of detecting smaller/weaker tornadoes (F0-F1) was greater than the detection of larger scale tornadoes (F2-F5) in rural areas. These findings are opposite of what would normally be expected because of the lower population density that exists in the rural areas. It would generally be expected that detecting smaller and/or weaker tornadoes would be more difficult in regions with a low population density because there would be fewer observers. In the regions of Atlanta, Des Moines, and Champaign, the results show the probability of detection of F2-F5 tornadoes is greater than that of F0-F1 tornadoes in rural areas. This is an expected result because regions that do not contain a high population density will be less likely to "spot" a small tornado than those that contain a higher population density. The region near Omaha was found to have reports that were too infrequent to estimate a population effect. Anderson et al. (2007) also suggested that the regions of Oklahoma City and Tulsa did not follow the expected results of having a higher probability of detecting F2-F5 tornadoes in low population density areas when compared to F0-F1 tornadoes because of the work that was done by the National Severe Storms Project (NSSP) beginning in the late 1950s. The NSSP sent research teams into the field in search of storms containing tornadoes. As a result, the rural communities in this region received an unexpected education related to tornadic storms and were therefore more likely to identify small tornadoes that would have been undetected in other rural regions included within this study. This trend continues today with numerous storm chasers concentrated in the Great Plains Region. This is a good example of the non-linear nature of tornado detection and population density at the CONUS scale.

Other studies have been conducted which focus on the correlation that exists between the increase in population and the increase in tornado reports. The western United States was found to have a strong correlation (0.96) between the total number of reported tornadoes and population growth (Frisbie 2006). When the number of reported tornadoes was restricted to stronger tornadoes ($\geq$ F2), there was actually a negative correlation with population. This is important because it reveals that a population bias is likely limited to the weaker F0-F1 tornadoes. This suggests that some of the increase in reported F0-F1 tornadoes may be a result of a growing population (more observers). The trend of increased reported F0-F1 tornadoes that is found in the west is comparable to the trend that is seen throughout the rest of the country (McCarthy and Schaefer 2004).

Recent improvements in the reporting of tornadoes may have improved the overall reporting statistics of the tornado database. However, these studies continue to clearly show an underestimate in the total number of tornadoes.

# CHAPTER III

# DATA AND METHODS

## Tornado Data

The tornado database obtained from the Storm Prediction Center (SPC) and National Climate Data Center (NCDC) contains the date and time of each tornado event, the county in which each tornado occurred, the Fujita rating, the number of injuries and fatalities, and the latitude and longitude of the genesis and dissipation locations. The use of this database will allow for a visual representation of the reported tornadoes throughout the United States to be developed. The Fujita Scale (Table 3.1) gives a description of each tornado category with an estimated wind speed and associated damage (Fujita 1971). The weaker F0 and F1 tornadoes often have a shorter storm track, making them more difficult to identify and thus creating a potentially greater observational bias. Some bias may also exist for strong tornadoes (F2, F3, F4, and F5). However, because of the normally longer track length, greater degree of damage created by the tornadoes, and other research pointing to population not having an impact on the reporting of strong tornadoes (Frisbie 2006 and Anderson et al. 2005), a decision was made to make weak tornadoes the primary focus of this study.

Table 3.1. Fujita Tornado Damage Scale. (Fujita 1971)

| Scale | Wind Estimate in MPH | Typical Damage |
|---|---|---|
| F0 | < 73 | Light Damage: Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged. |
| F1 | 73 – 112 | Moderate Damage: Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads. |
| F2 | 113 – 157 | Considerable Damage: Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground. |
| F3 | 158 – 206 | Severe Damage: Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown. |
| F4 | 207 – 260 | Devastating Damage: Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated. |
| F5 | 261 – 318 | Incredible Damage: Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 meters (109 yards); trees debarked |

**Census Data**

Census data will allow for a visual representation of where high and low county population density areas are located throughout the country. Census data collected will be from the years 1970, 1980, 1990, and 2000. These data will be used in conjunction with the tornado data for the purpose of locating regions of the country that have an under representation of tornado reports resulting from low population densities. The census data also contains county education levels that will be used to determine if any relationship exists between the number of reported tornadoes and the level of education that exist within each county. The three levels of education used in this study determine the percentage of the county without a high school diploma, the percentage with a high school diploma, and the percentage with at least one year of college. These three education percentages will then be used with the tornado data in order to determine if any relationship exists between a county's education level and the number of reported tornadoes.

**Study Period and Study Area**

The study period chosen for this project are the years 1970-2005. Both tornado and census data are available for the years 1950-2005, but a decision was made to use only the years 1970-2005 as this period contains the most reliable tornado data. Using the first several years of this database may have yielded a larger and more complete database, but the reliability of these data would have raised validity issues with the results. Using only the last decades of the tornado database, while potentially more accurate, would not allow for a complete and thorough analysis of the geographic distribution of reported tornadoes. Furthermore, the use of this data period allows census data to be used in conjunction with the tornado data so that relationships between population and reported tornadoes may be identified.

The area of study for this project is the Continental United States. The areas of Dixie Alley and Tornado Alley were also chosen and examined in greater detail in order to find relationships between population and tornado reporting. These two regions were chosen because of the large number of tornadoes that occur and because the counties within these areas are similar in size. Dixie Alley and Tornado Alley are often loosely defined areas that are based off of "personal" perception (Gerard et al. 2005). For this study, Tornado Alley will be defined as the states of Kansas, Nebraska, Oklahoma, and South Dakota. Dixie Alley will be defined as the states of Alabama, Georgia, and Mississippi. Although other states such as Louisiana, Arkansas, and Texas are often included in these defined areas, they will be omitted in this study in order to create a geographic separation between the two sub-regions of study.

**Tornado and Population Relationships**

Various statistical and spatial techniques will be employed in an effort to identify population and tornado relationships. A county's FIPS (Federal Information Processing Standards) code was the common field used to match the tornadoes with the county in which they occurred. Before analyzing for relationships, the tornado density and population density will be calculated and displayed as a choropleth map using GIS

ArcMap in order to visually analyze the distribution of tornadoes and population throughout the United States. The tornado density will be calculated for each county by dividing the total number of tornadoes by the county's total area in kilometers. The population density will be calculated for each county by dividing the total number of people by the total area in kilometers.

*Buffers*

Maps of all weak (F0&F1) tornadoes between 1970-2005 will be constructed with GIS ArcMap in order to determine if a proportionally higher number of tornadoes is reported near higher populated cities and interstate highways compared with the rest of the Continental United States. The weak tornadoes will be extracted from the tornado database during this statistical analysis in order to determine if the number of reports of tornadoes are more biased toward higher populated areas. Buffers will be placed around the cities and interstate highways in order to find the number of tornadoes reported within these specified bounds. The buffers will extend out from the center of the interstate highways and cities, and as a result a 5.0 km buffer would have a diameter of 10.0 km.

Highways will be assigned a 1 km, 2.5 km, and 5.0 km buffer. The determination was made to use these three lengths because this is likely the approximate distance depending on vegetation and terrain an observer would be able to accurately spot and report a tornado from the interstate highways. Human observance of tornadoes could also potentially be higher within these buffered areas because residential density is often higher along interstate highways. Three different sized buffers were chosen in order to determine if there was an increase in reported tornadoes within a closer distance to the interstate highways. After finding the number of tornadoes within the specified bounds, the percentage of total tornadoes within the bounded area will be compared to the percentage of total land within the bounded area. Assuming a random distribution, the percentage of weak tornadoes within these buffers would be equal to the percentage of land within the United States that these buffers encompass. Interstate highways do not follow meteorologically favored regions for tornadoes and therefore should not have a higher number of tornadoes associated with them as compared to non-interstate regions of the United States. This interstate buffer method will be conducted using the entire Continental United States, but will also be used for all land east of a north/south running line through Denver, Colorado and all land west of the same north/south line.

This same method will be conducted for cities throughout the United States. Buffers will be placed around cities with populations of at least 25,000, 50,000, and 100,000. Three different sized population thresholds were chosen for the purpose of determining if tornadoes were more commonly reported as population increased. Buffers of 2.5, 5.0 km, and 10.0 km were chosen because this is an appropriate distance from the center of the city in which the bulk of its population would be able to see and report a tornado. Different sized buffers were used in order to find if reporting increased in a more confined area closer to the center of the city where population is usually of greatest density. After finding the number of tornadoes within each buffer, the percentage of total tornadoes within the bounded area will be compared to the percentage of total land within the bounded area. This procedure will also be conducted for the same three regions used for the interstate highways.

*T-Tests*

A two-sample T-test assuming equal variance will be used in order to determine if there is a significant difference between the tornado densities of counties with high population density vs. the tornado densities of counties with low population density. Only weak tornadoes are used for these tests for reasons previously mentioned. This test will be conducted using the study areas of the Continental United States, Tornado Alley, and Dixie Alley. Individual states within Tornado Alley and Dixie Alley will also be tested. The population density and tornado density will be calculated for each county in the tested area. The median of the population densities will be calculated in order to find a "breakpoint" for counties with "high" population and "low" population. In order to establish a meaningful gap between high and low population, a difference of 5 persons $km^{-2}$ is created as an artificial breakpoint for the two sets of data. Therefore, a region with a population density median of 23.76 persons $km^{-1}$ will utilize threshold values of 25.00 and 20.00 for the respective high and low population densities. After developing the two distinct groups of population densities, the corresponding tornado densities will be tested to find if a significant difference exists between the two groups. Tornado and census data from the 70s, 80s, 90s, and 00s will be used for these tests. In order to keep consistency between the four decadal periods, a correction factor will be applied to the partial decade of the 00s. The total number of tornadoes for each county will be multiplied by a value of 1.4 in order to represent a full decade.

*Discriminant Analysis*

In order to determine if the education level of a population influences the number of tornadoes a county reports, discriminant analysis will be conducted. Each county's education level will be determined by calculating the percentage of a county's population with no high school diploma, a high school diploma, and at least one year of college education. After this percentage is found, the education level of each county within the predetermined study area will be tested against the tornado density of each county. The tornado density of each county will be given a 0 or a 1 depending on whether its value is less than or greater than the median found for the tested study region. This will be done for the purpose of testing if education level is a significant factor in predicting if a particular region will report a high (1) or low (0) number of tornadoes.

CHAPTER IV

# RESULTS AND DISCUSSION

## Tornado Distribution Analysis

Finding relationships between population and weak tornadoes requires a thorough understanding of the distribution of tornadoes. Therefore, all weak tornado events (F0 and F1) for the period 1970-2005 were extracted from the historic tornado database and displayed with GIS ArcMap. A visual inspection of the displayed tornadoes (Figure 4.1) during this study period shows an expected high distribution in the Great Plains and Southeast Regions of the United States. Weak tornado density was also displayed by decade (Figure 4.2-4.5) in order to determine if any possible changes or trends in the distribution of tornadoes occurred throughout this period. Ten classes with quantile breaks were used to display these densities. The quantile break method ranked the calculated tornado densities and grouped them evenly into the ten classes. Although there is likely some variation in the distribution of tornado density between decades, a noticeable difference is not apparent.

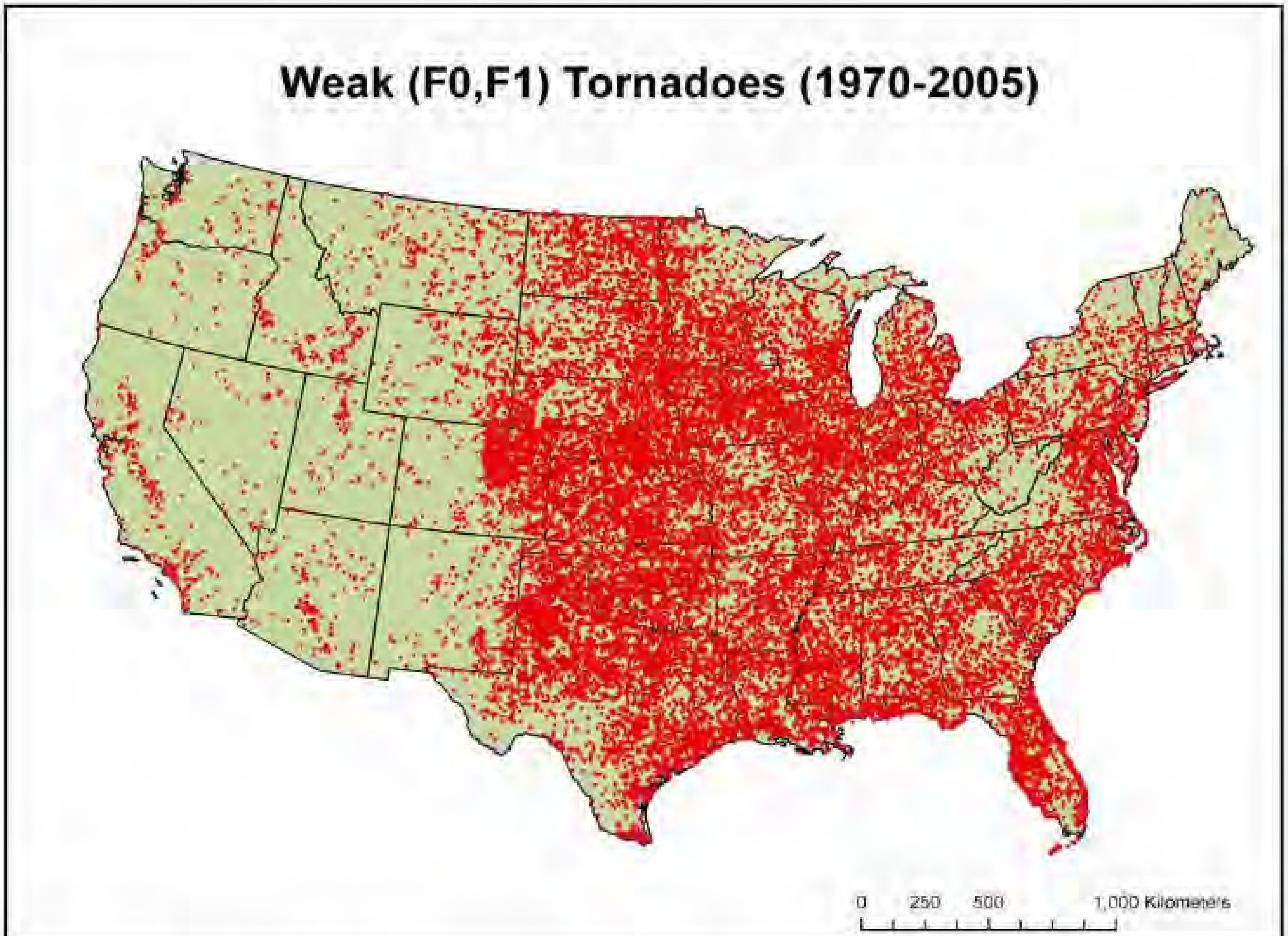


Figure 4.1. Distribution of all weak tornadoes (1970 –2005).

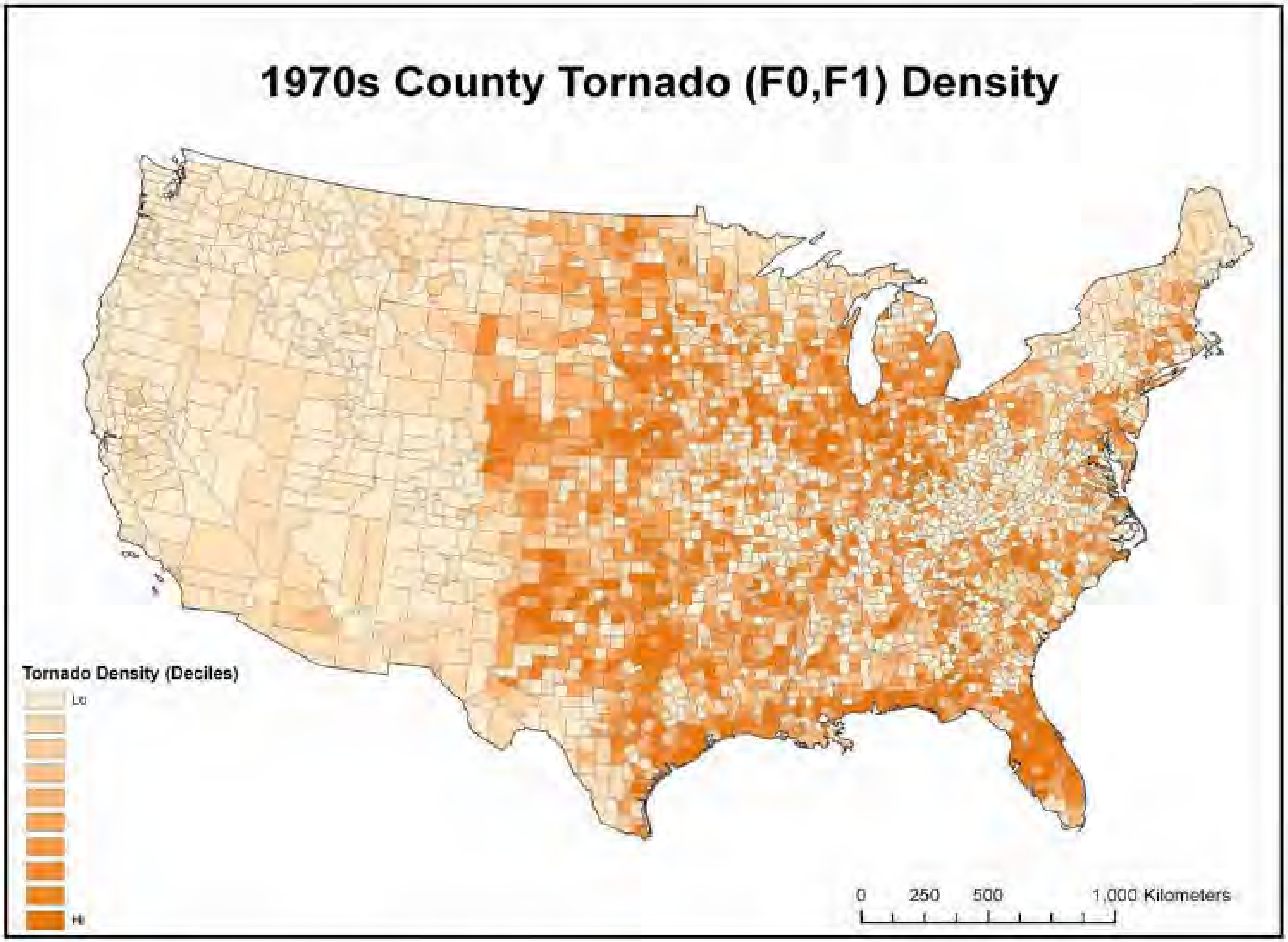


Figure 4.2. Distribution of 1970s weak tornado density.

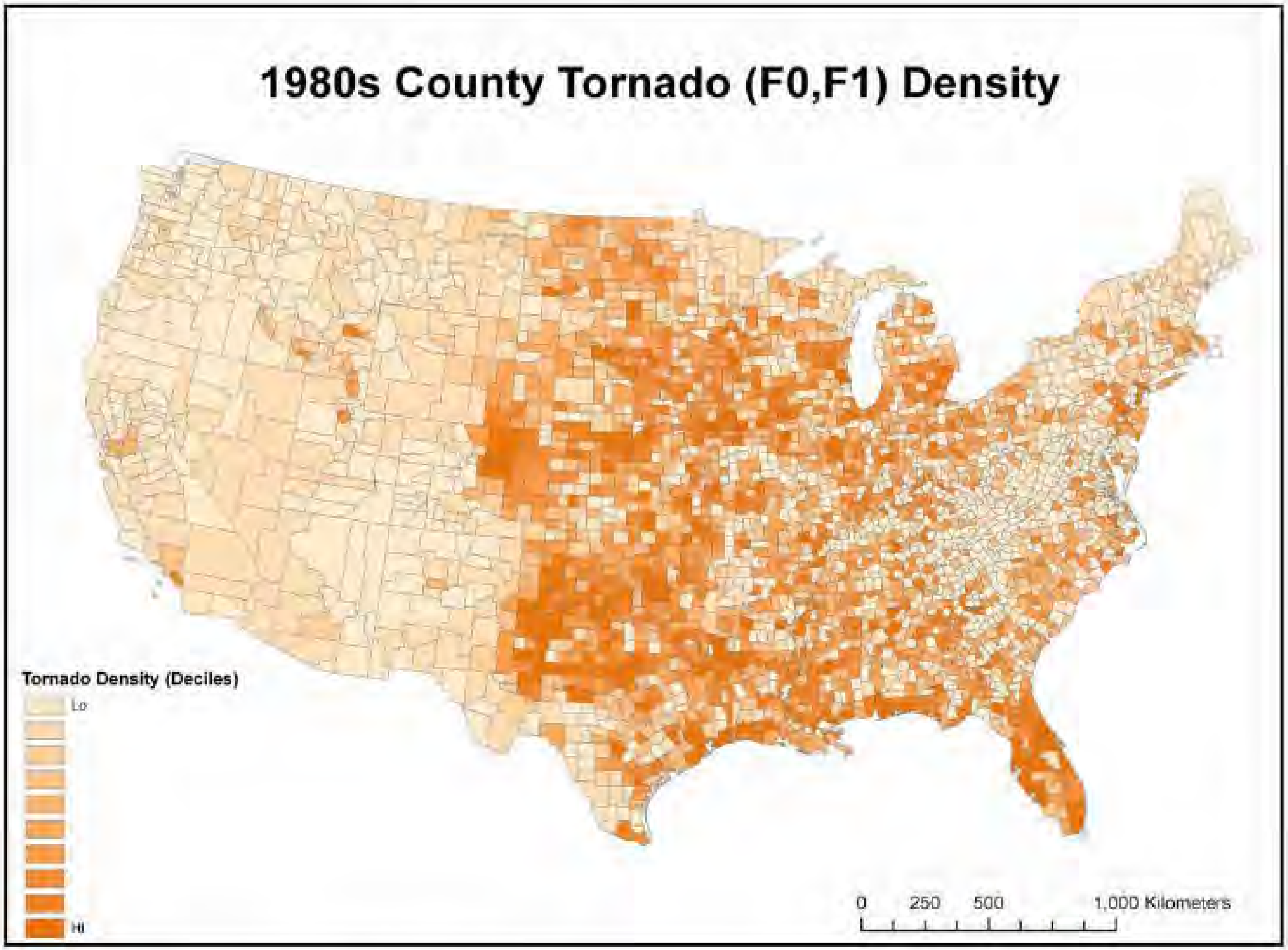


Figure 4.3. Distribution of 1980s weak tornado density.

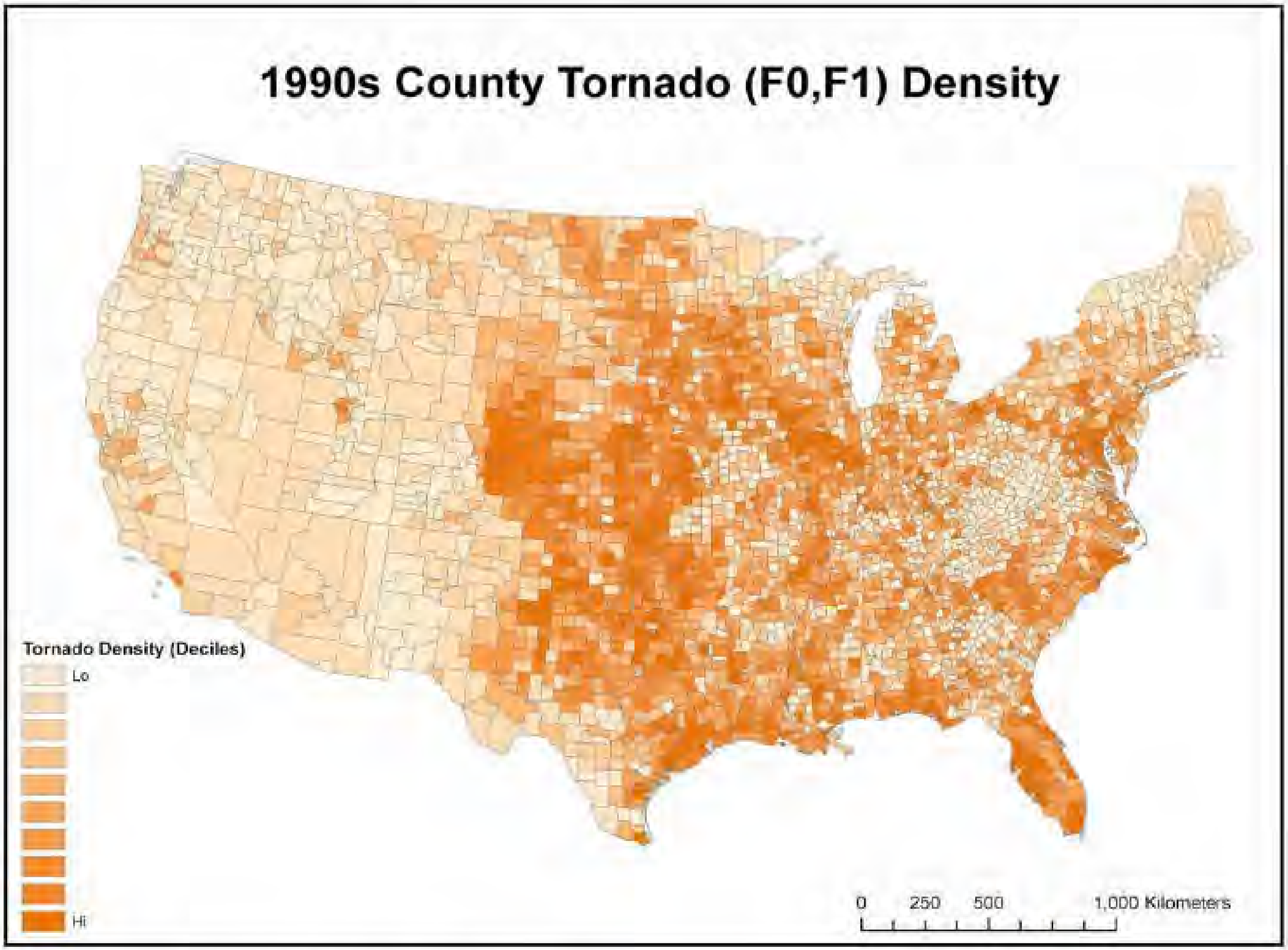


Figure 4.4. Distribution of 1990s weak tornado density.

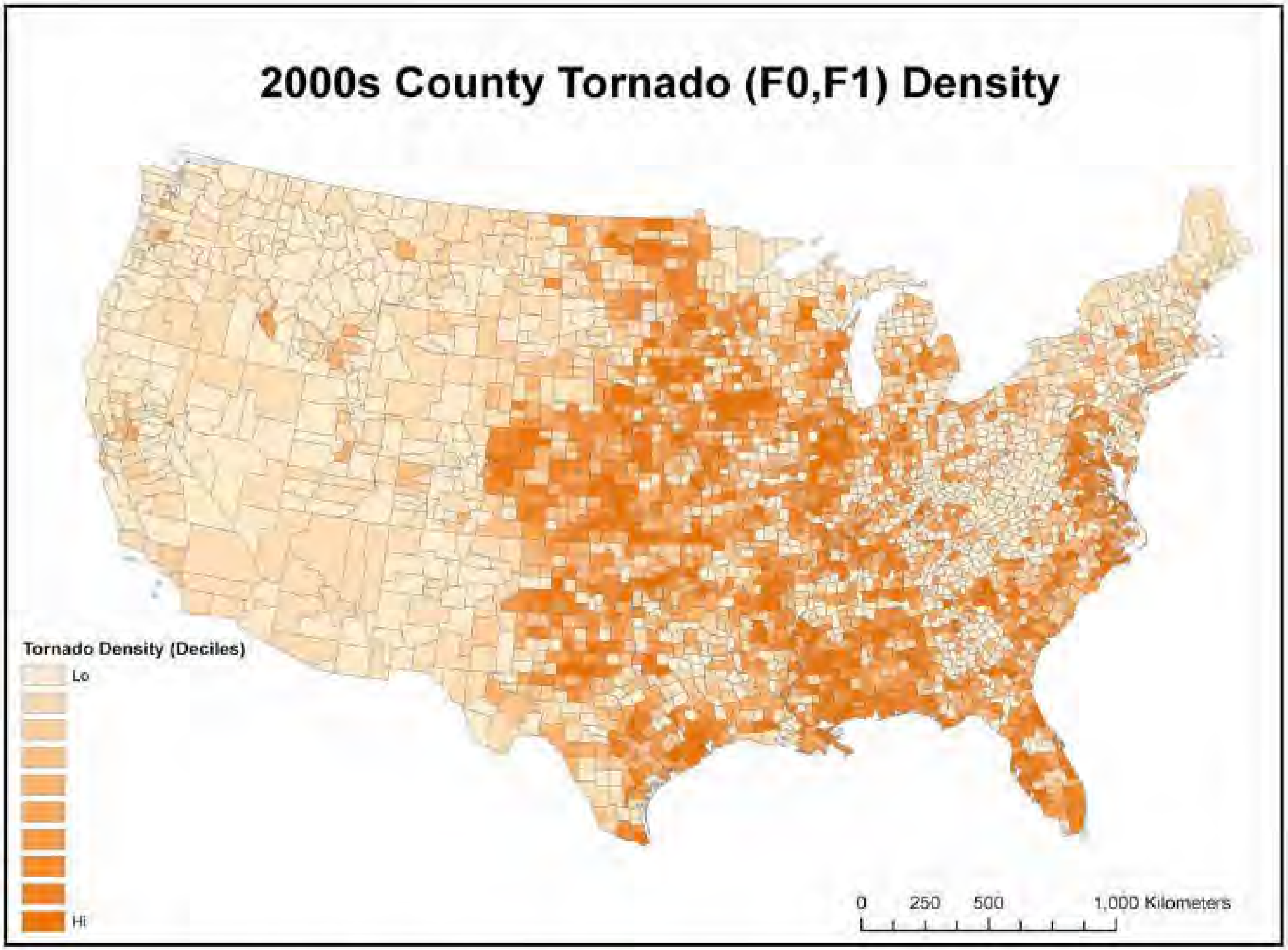


Figure 4.5. Distribution of 2000s weak tornado density.

**Population Distribution Analysis**

The distribution of population density is also analyzed in order to identify relationships between tornadoes and population. The population density was calculated for each county and displayed with GIS ArcMap. Figures 4.6-4.9 show the decadal distribution of population density throughout the Continental United States.
These maps show that population densities vary widely, but are generally higher in the eastern half of the United States than in the western half. Most of the higher population density counties are located in areas of the Northeast, Florida, and the West Coast. However, there are counties dispersed throughout areas of the U.S. such as the Great Plains and Midwest that have spikes in population density that may potentially have an influence on the frequency of reported tornadoes in the United States. The constructed choropleth maps show that there is not a noticeable change in the distribution of tornado density throughout the United States during the four displayed decades. While the census database indicates a growth in population and therefore population density during this time period, the applied quantile breaks indicates that the relative density changed very little when comparing one decade to the other.

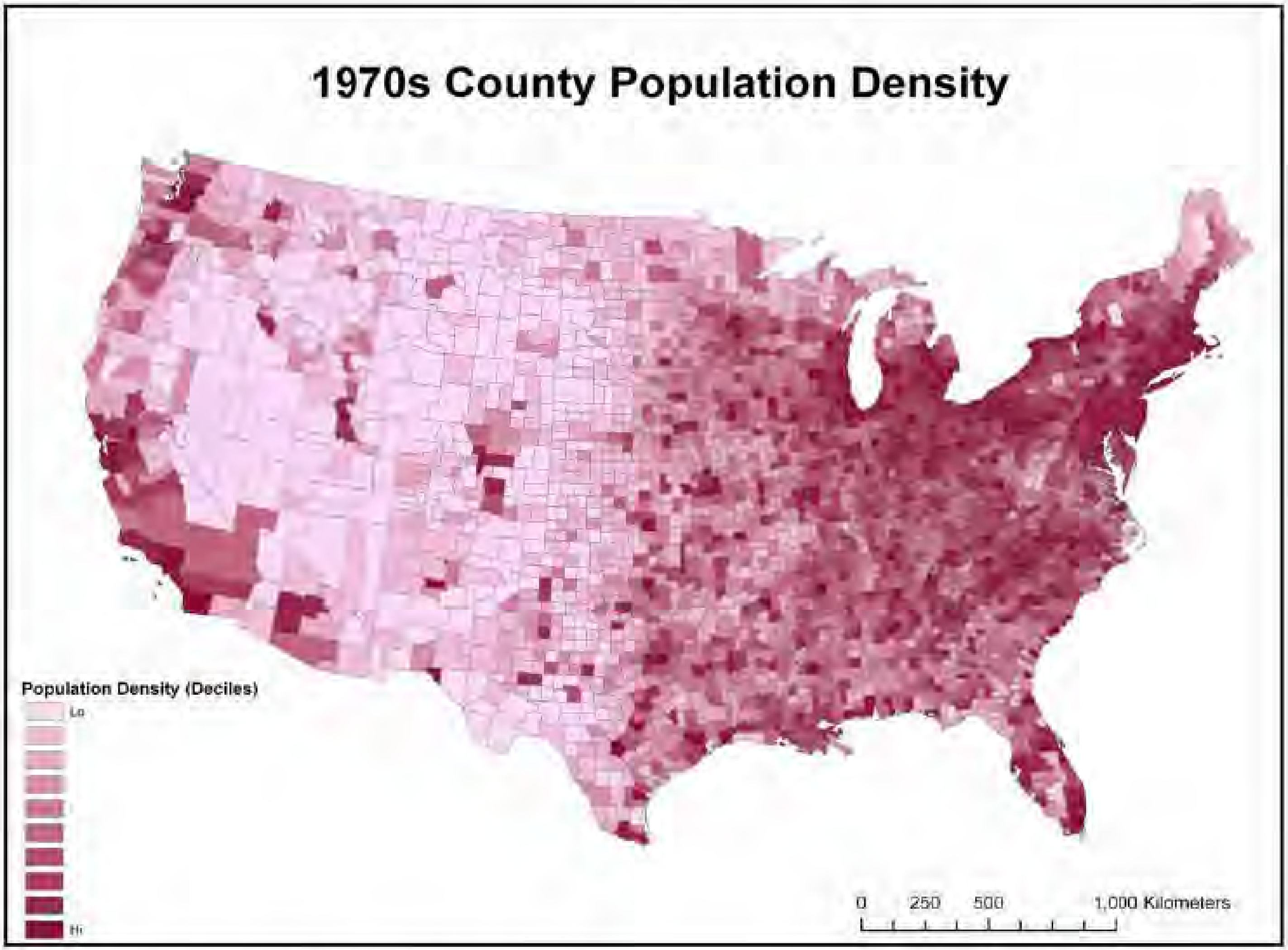


Figure 4.6. Distribution of 1970s population density.

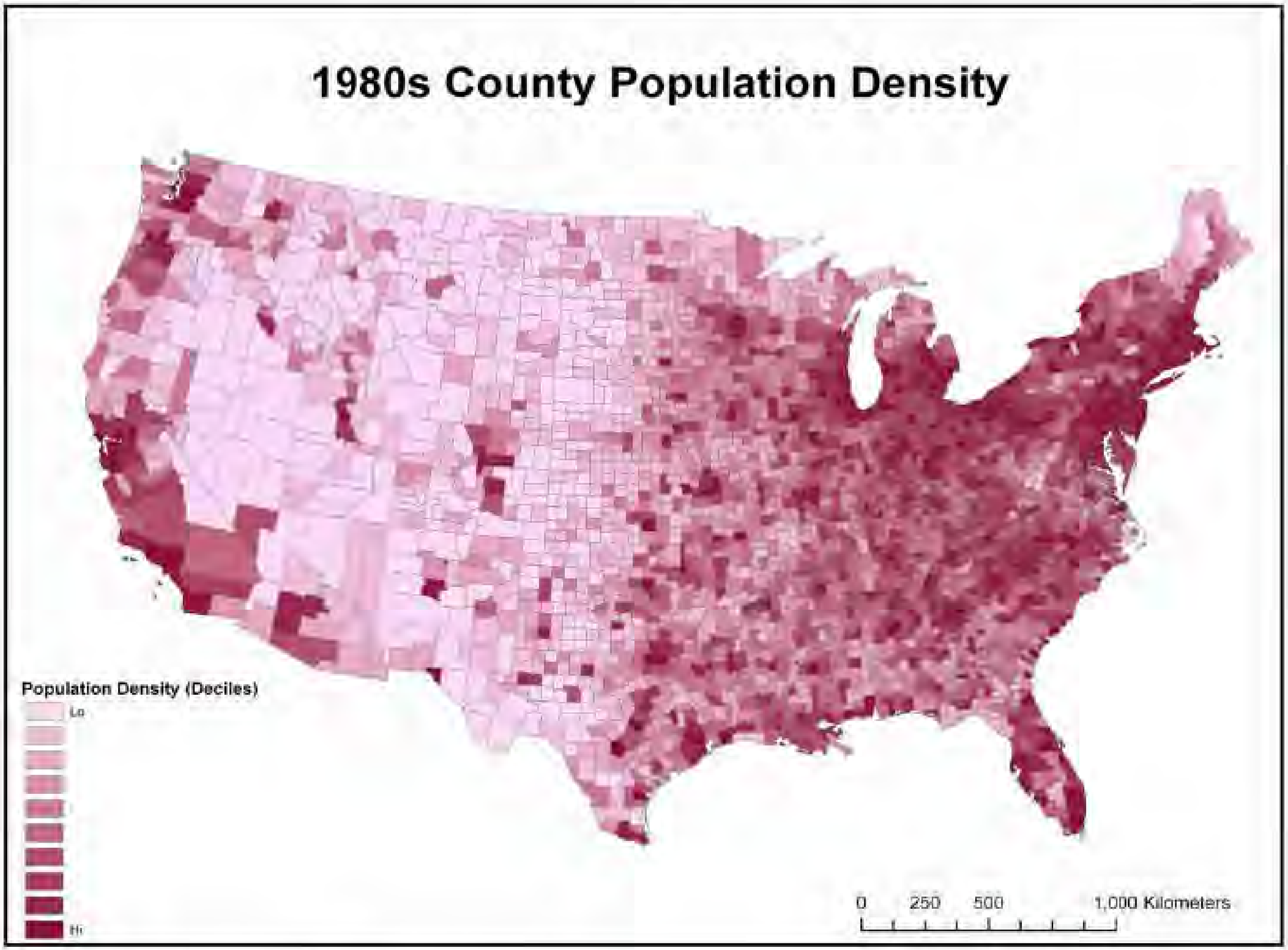


Figure 4.7. Distribution of 1980s population density.

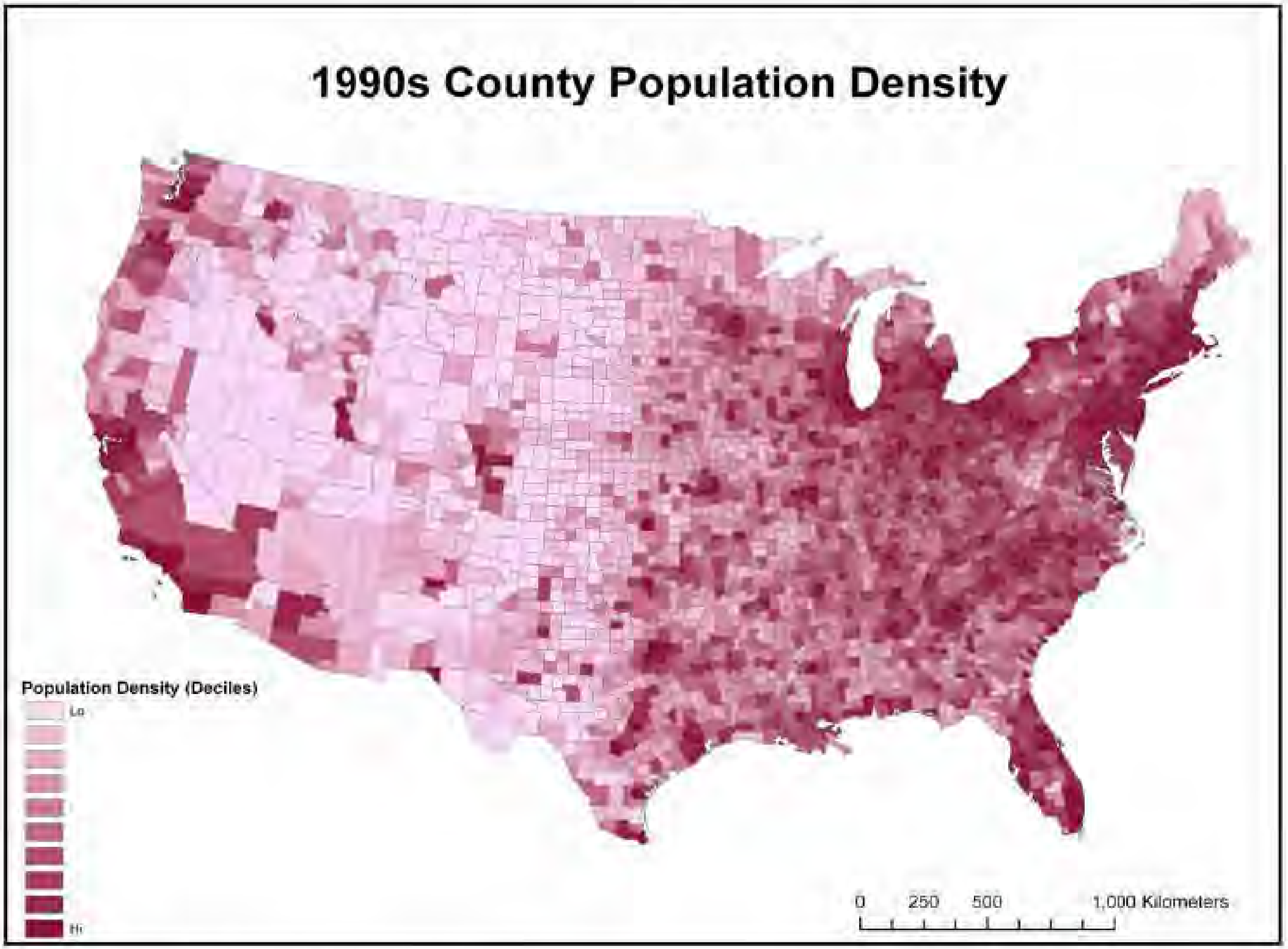


Figure 4.8. Distribution of 1990s population density.

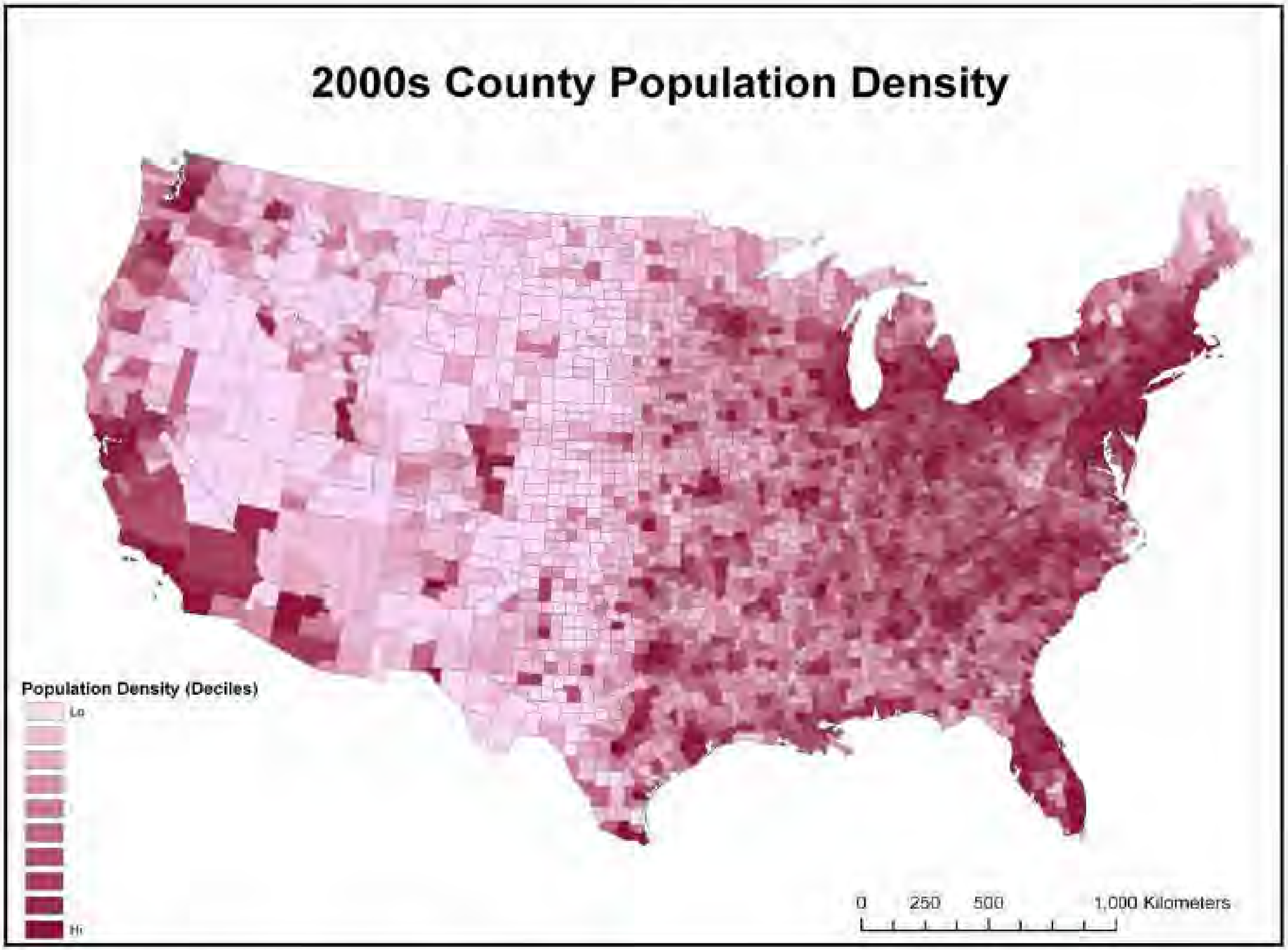


Figure 4.9. Distribution of 2000s population density.

**Highway Buffer Analysis**

Buffers were constructed in order to find if any relationships existed between the number of tornadoes reported and their proximity to interstate highways in the United States. Buffers of 1.0, 2.5, and 5.0 km were chosen for interstates. The three buffers sizes were chosen because it is unclear how far the average visible distance would be throughout the U.S. Some areas would likely have a longer visibility distance than others. For example, a traveler along an interstate in the relatively flat Great Plains region would be able to see much farther than a traveler in a location with a lot of vegetation and or hills obstructing their view. Table 4.1 shows the percentage of all weak tornadoes that occurred within the specified buffers surrounding major interstate highways compared to the percentage of total land that these buffers encompassed within the Continental United States. The results in Table 4.1 show that there is a much higher percentage of tornadoes within these highway buffers than what would be expected in a random distribution considering the amount of land area the buffer contains.

For the entire Continental United States, the percentage of tornadoes within the specified highway buffer is nearly double what one would expect considering the amount of land the buffer encompasses. When focusing on the region east of Denver, CO, the percentage of tornadoes within the specified buffers are also greater than expected. However, the ratios between the percentage of tornadoes to the percentage of land is not quite as large as the calculated ratios for the entire Continental United States.

In the region west of Denver, CO, the percentage of tornadoes within the specified buffers is much greater than expected. In fact, when calculating the percentage of tornadoes in a 2.5 km and 5.0 km buffer, the ratio of tornadoes to land is nearly 4:1. This maybe a result of the western U.S. having a lower population density and therefore having a larger percentage of the population congregated around interstates.

Figures 4.10–4.12 displays the three different sized buffers used in this study and the distribution of tornadoes within them. When examining the calculated ratios between tornado and land percentage, there was little change regardless of buffer size used.

Table 4.1. Highway proximity relationships with weak tornadoes

| | **Continental U.S.** | | | **Eastern U.S.** | | | **Western U.S.** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Proximity Distance** | Land | Tornado | Ratio | Land | Tornado | Ratio | Land | Tornado | Ratio |
| **1.0 km** | 1.8% | 3.4% | 1.89:1 | 2.2% | 3.3% | 1.50:1 | 1.2% | 4.1% | 3.42:1 |
| **2.5 km** | 4.5% | 8.4% | 1.87:1 | 5.4% | 8.1% | 1.50:1 | 3.1% | 13.5% | 4.35:1 |
| **5.0 km** | 9.0% | 16.0% | 1.78:1 | 10.8% | 15.3% | 1.42:1 | 6.2% | 27.0% | 4.35:1 |


Figure 4.10. Distribution of weak tornadoes within 1 km of an interstate.

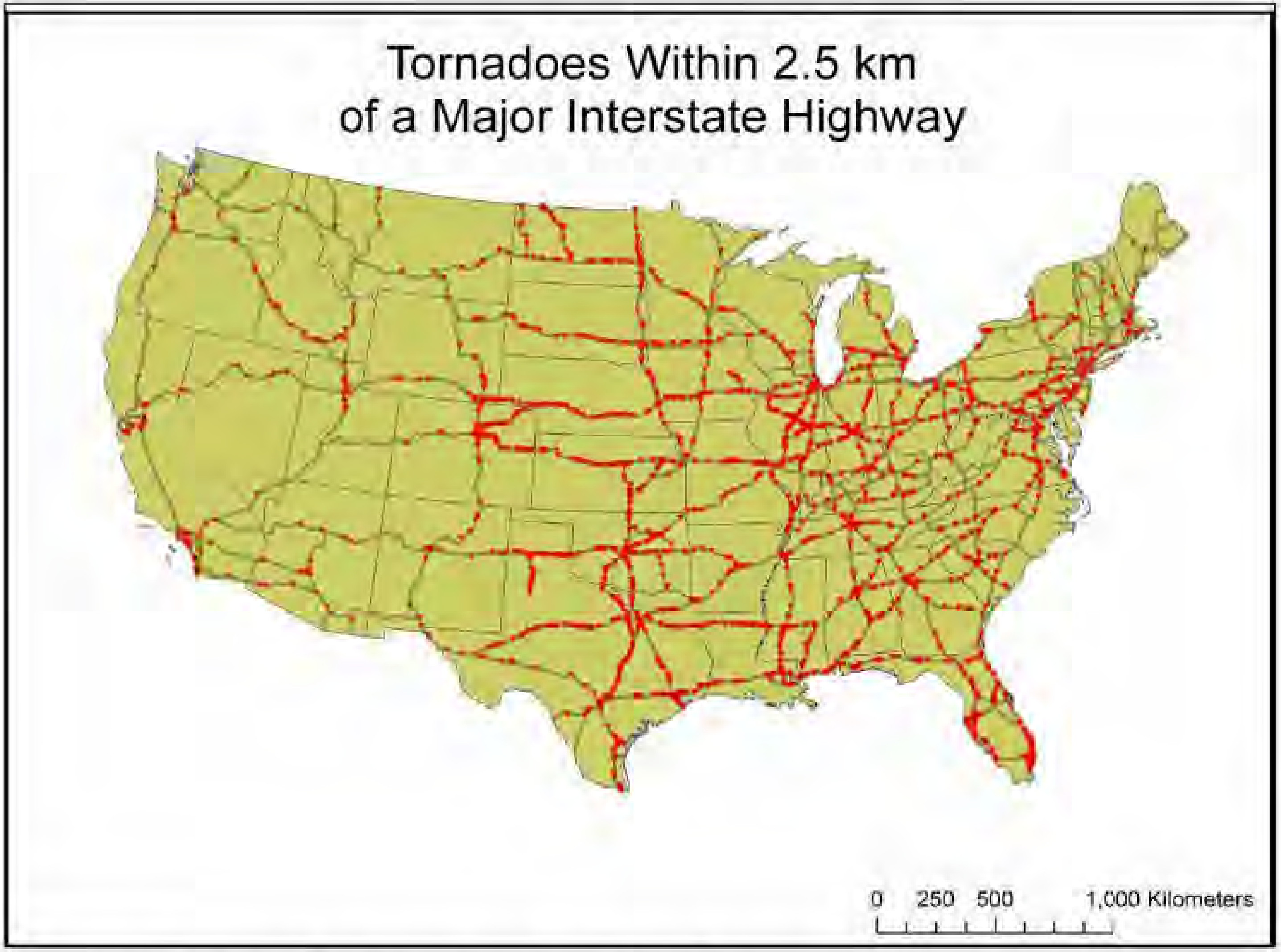


Figure 4.11. Distribution of weak tornadoes within 2.5 km of an interstate.


Figure 4.12. Distribution of weak tornadoes within 5 km of an interstate.

**City Buffer Analysis**

Buffers (2.5,5.0,10km) were also used in the study in order to find if any relationship existed between the number of tornadoes reported and their proximity to cities in the Continental United States. Figures 4.13-4.15 show the three different sized buffers used in this study and the distribution of tornadoes within them. Table 4.2 compares the percentage of total land area that is encompassed by the designated buffers with the percentage of weak tornadoes that are within these buffers. In a random distribution, one would expect that the percentage of all weak tornadoes should approximate the percentage of land within the buffer. However, these calculations show that the percentage of tornadoes that is reported within these city buffers is much greater than the land percentage of these buffers. Calculating a tornado percentage vs. land percentage ratio shows the degree to which the number of tornado reports are higher than expected. These ratios also show two noticeable trends. The ratio increases when the buffer is restricted to the smallest distance around the city and when the buffer is restricted to cities of higher population. During this study, the largest ratio was calculated for the cities with the largest population threshold (100,000) and the smallest buffer (2.5km). The calculated ratio for this condition was 7.8:1.

Finding higher tornado percentages than land percentages was not surprising considering the results from the highway proximity statistics pointed to an apparent countrywide observational bias related to tornado reporting. However, the degree in which the tornado percentages were higher when compared to the land percentages is surprising. In fact, there was only one condition tested in which the results did not yield a scenario in which the ratio of tornado percentage to land percentage was at least two to one within the specified buffer. The condition that did not yield this relationship was for cities with a buffer of 10 km and a population of at least 25,000. It is not surprising that this yielded the smallest ratio of 1.75:1 given the larger area and smaller population. It was also particularly interesting that the ratios increased as the buffer size was reduced and the population was increased. This seems to be a direct result of population density influencing the reporting of tornadoes. The higher the population, and the closer the buffer is constricted around the more densely populated center of the city, the chance of someone seeing and properly reporting a tornado becomes much greater.

In order to find a more regional relationship between the number of tornadoes reported and proximity to a city, the country was split with a north/south line running through Denver, CO serving as the dividing line. This was done because of the obvious difference in the displayed tornado climatology between the two regions. Figure 4.1 shows how few tornadoes occur in the west compared to the east. Table 4.3. shows that there are still far more tornadoes reported in close proximity to cities in the Eastern U.S. than expected. When comparing land percentage to tornado percentage within the specified area, it becomes clear that the high population and related observation that exists close to the city has a large impact on the frequency with which tornadoes are reported. The general trend shows that the larger the city and the closer in proximity you are to it, the more tornadoes will be reported.

Analyzing the Western United States revealed a very strong relationship between the proximity to a city and the number of tornadoes that are reported. This relationship was much stronger than what was found for the Continental U.S. Again, the larger cities and closer proximity distances indicate the strongest relationship. Table 4.4 shows the degree in which tornado reporting is higher than expected considering the land percentage that is being analyzed. The most staggering finding was the result from the analysis done for cities of at least 100,000 and a proximity distance of 2.5 km. This finding showed that a tornado is 22 times more likely than expected in a random distribution. The smallest ratio found between land and tornado percentage was for the analysis conducted for cities of greater than 25,000 and proximity distance of 10 km. Even though this produced the smallest ratio, it still showed that a tornado was 3.5 times more likely to be reported in this region than elsewhere in the study region.

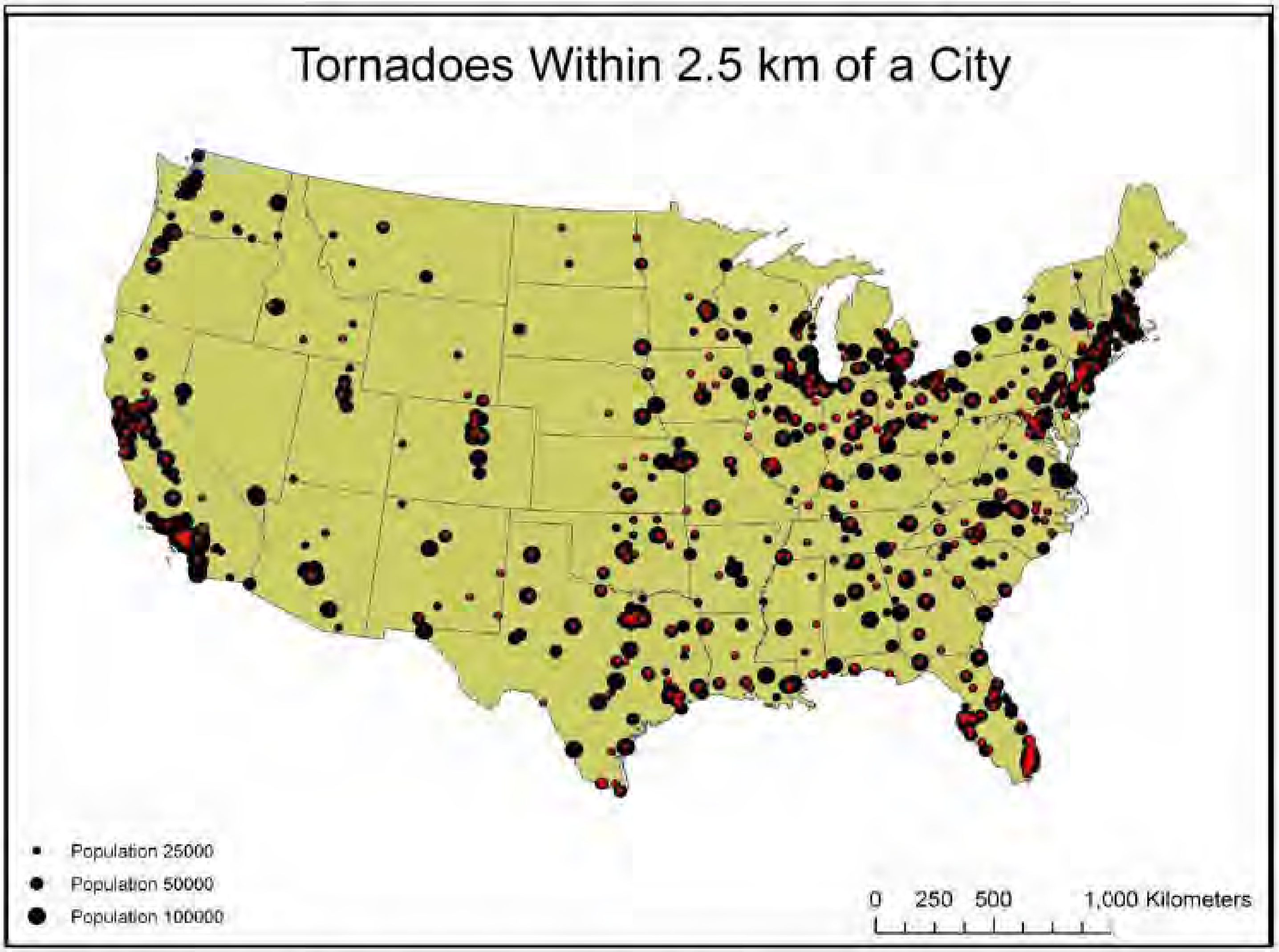


Figure 4.13. Distribution of weak tornadoes within 2.5 km of a city.

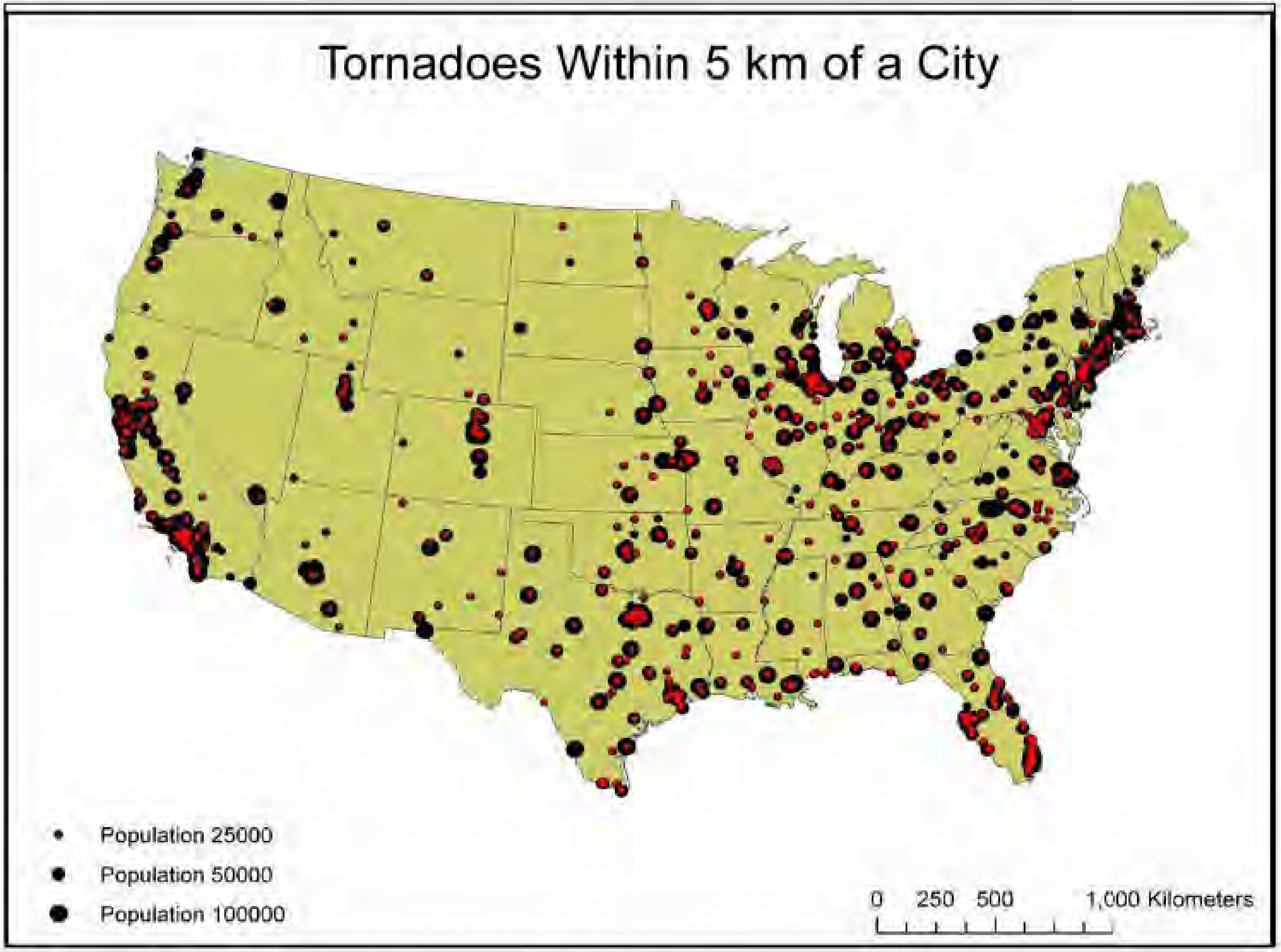


Figure 4.14. Distribution of weak tornadoes within 5 km of a city.

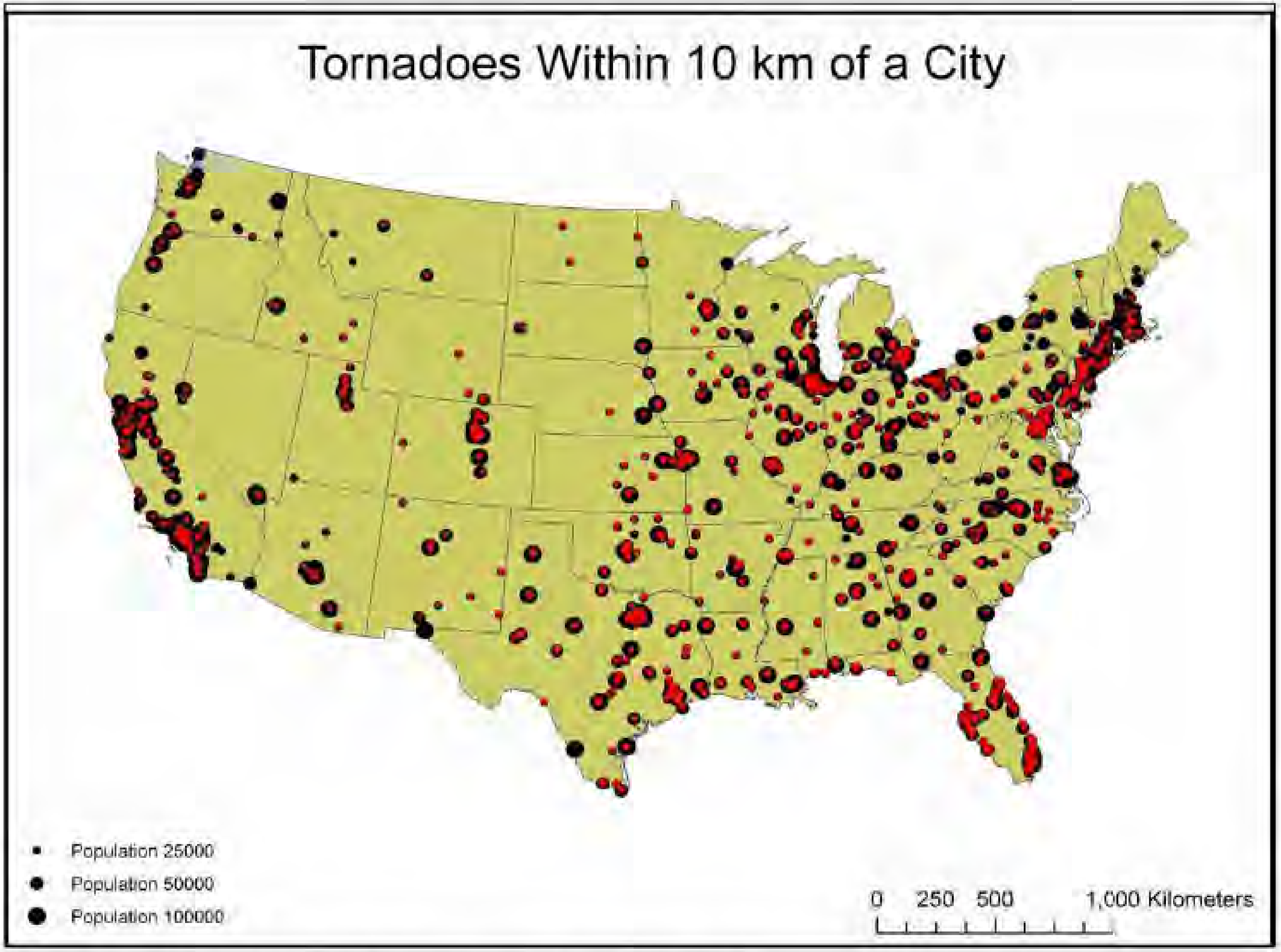


Figure 4.15. Distribution of weak tornadoes within 10 km of a city.

Table 4.2. City proximity relationships for weak tornadoes in the Continental United States.

| | **Population 25,000** | | | **Population 50,000** | | | **Population 100,000** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Proximity Distance** | Land | Tornado | Ratio | Land | Tornado | Ratio | Land | Tornado | Ratio |
| **2.5 km** | 0.33% | 2.15% | 6.52:1 | 0.14% | 0.93% | 6.64:1 | 0.05% | 0.39% | 7.80:1 |
| **5.0 km** | 1.31% | 4.83% | 3.69:1 | 0.56% | 2.51% | 4.48:1 | 0.20% | 1.11% | 5.55:1 |
| **10.0 km** | 5.24% | 9.17% | 1.75:1 | 2.24% | 5.27% | 2.35:1 | 0.81% | 2.41% | 2.98:1 |

Table 4.3. City proximity relationships for weak tornadoes in the Eastern United States.

| | **Population 25,000** | | | **Population 50,000** | | | **Population 100,000** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Proximity Distance** | Land | Tornado | Ratio | Land | Tornado | Ratio | Land | Tornado | Ratio |
| **2.5 km** | 0.37% | 2.05% | 5.54:1 | 0.15% | 0.87% | 5.80:1 | 0.05% | 0.34% | 6.80:1 |
| **5.0 km** | 1.47% | 4.63% | 3.15:1 | 0.61% | 2.35% | 3.85:1 | 0.21% | 1.03% | 4.90:1 |
| **10.0 km** | 5.92% | 8.87% | 1.50:1 | 2.20% | 4.99% | 2.67:1 | 0.85% | 2.17% | 2.55:1 |

Table 4.4. City proximity relationships for weak tornadoes in the Western United States.

| | **Population 25,000** | | | **Population 50,000** | | | **Population 100,000** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Proximity Distance** | Land | Tornado | Ratio | Land | Tornado | Ratio | Land | Tornado | Ratio |
| **2.5 km** | 0.25% | 3.73% | 14.92:1 | 0.12% | 2.11% | 17.58:1 | 0.05% | 1.10% | 22.00:1 |
| **5.0 km** | 0.99% | 8.01% | 8.09:1 | 0.48% | 4.95% | 10.31:1 | 0.19% | 2.50% | 13.16:1 |
| **10.0 km** | 4.01% | 14.02% | 3.50:1 | 1.90% | 9.80% | 5.16:1 | 0.74% | 6.29% | 8.50:1 |

T-Tests Analysis

Two-sample T-tests assuming equal variance were used for the purpose of determining if a significant difference existed between tornado densities of counties with low population densities and tornado densities of counties with high population densities. Finding a significant difference between these two calculations would lead to the determination that densely populated counties have a higher rate of tornado reporting than counties that contain lower population density. T-Tests were conducted for the entire U.S. and sub-regions throughout the country. The mean tornado density for counties with high population density versus counties with low population density along with the T-value and significance are shown for each represented study area in the tables below. In order to determine if a county contained a high or low population density, the median of all the county population densities within the tested regions was calculated in order to establish a breakpoint. In order to establish a meaningful gap between high and low population, a difference of 5 persons $km^{-2}$ was created for the two sets of data. The two-sample T- test was conducted for the four decadal periods of the 70s, 80s, 90s, and 00s in order to determine if any trend or improvement has developed for the tested study area.

*Continental United States*

Table 4.5 shows the mean tornado density for counties with a defined high population density is higher than the mean tornado density for counties with a defined low population density in each of the four tested decades. The calculated T- values show that this difference of means is significant for all tested decades in the Continental United States ($\alpha$<0.01). In other words, it can be stated with 99% confidence that the mean tornado density for low population density counties is significantly lower than the mean tornado density for high population density counties. Mean tornado densities within this study area increase throughout the period of study until the 2000s decade. This is likely an indication that many of the tornadoes that were once going undetected are now being detected and reported. However, the difference between the mean tornado density of the low and high population counties is still significant at $\alpha$ <0.01 in the 2000s. It can therefore be concluded that although the relationship may not be as strong as it was in the 70s, a significant countrywide relationship continues to exist between tornado reporting and population.

Table 4.5. Test of significance for county tornado densities (per 1000 $km^2$) between high and low population counties in the Continental United States.

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 1.958 | 3.55 | 11.08 | ** |
| **80s** | 2.498 | 3.36 | 5.06 | ** |
| **90s** | 4.005 | 5.612 | 4.74 | ** |
| **00s** | 4.092 | 5.324 | 3.67 | ** |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

*Dixie Alley and Tornado Alley*

Although a countrywide significant difference was shown to exist between the mean tornado density of counties with high versus low population density, it would be helpful to have a more detailed understanding of the relationship that exists for areas of the country with heightened tornado frequency. An examination of the tornado climatology and literature since 1970 reveals that the highest tornado frequency has occurred throughout the two regions of Dixie Alley and Tornado Alley. Because of the research conducted in these regions, an accurate tornado climatology is more important in these areas. It is therefore helpful to know if there is a significant relationship between tornado reporting and population within these areas. Furthermore, it is useful to know if there are any similarities or differences between these two areas of study in regards to the relationship between population and tornado reporting.

Tables 4.6 and 4.7 show the mean tornado density for counties with high population density vs. counties with low population density along with the T-value and significance for each of the four decades. The counties of Dixie Alley that have been designated as having a high population density contain a higher mean tornado density than the low population density counties for each of the four tested decades. Also, with the exception of the 2000s, all tested time periods contain a significant difference between the mean tornado density of the low population density counties and the mean tornado density of the high population density counties at $\alpha < 0.01$. The same results are found for the counties of Tornado Alley. All of the tested decades contain higher mean tornado densities in the high-population density counties than in the low-population density counties. Also like Dixie Alley, the difference between the mean tornado density of the high and low population density counties is significant at $\alpha < 0.01$. One noticeable difference between these two regions is that Tornado Alley contains a higher tornado density during the period of study than Dixie Alley. However, they both share a similar trend in tornado density throughout this period. The mean tornado density of both regions has a noticeable increase until the most recent decade. This is particularly interesting because this also marks the decade in which the difference between the mean tornado densities of the high and low populated counties is no longer significant. This is likely an indication that heightened population densities within these regions no longer significantly influences the number of tornadoes being reported. If this is the case, we may be seeing a decrease in the non-meteorological factors such as population significantly influencing tornado reports.

Table 4.6. Test of significance for county tornado densities (per 1000 $km^2$) between high and low population counties in Dixie Alley.

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 1.805 | 3.789 | 5.26 | ** |
| **80s** | 2.355 | 3.928 | 4.16 | ** |
| **90s** | 3.219 | 4.787 | 3.43 | ** |
| **00s** | 3.580 | 4.336 | 1.56 | |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

Table 4.7. Test of significance for county tornado densities (per 1000 $km^2$) between high and low population counties in Tornado Alley.

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 2.799 | 4.335 | 4.66 | ** |
| **80s** | 3.284 | 5.287 | 4.57 | ** |
| **90s** | 6.205 | 8.989 | 4.69 | ** |
| **00s** | 6.371 | 7.448 | 1.23 | |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

*Alabama*

Although the region of Dixie Alley indicates significant differences related to population density and reported tornadoes, an understanding of this relationship was not known on the state level. The state of Alabama was tested in order to find if a significant difference existed between the mean tornado densities of low population density counties and high population density counties. Table 4.8 shows that not all decades in the state of Alabama had a significant difference in the tornado density between high and low population density counties. In the regional analysis of Dixie Alley, the 2000s decade was the only period of time tested that did not contain a significant difference between the mean tornado density of the high and low population density counties. However, in the state of Alabama, the 1980s was the only decade that did not contain a significant difference at $\alpha < 0.05$. The 90s and 00s were significantly different at $\alpha < 0.05$. The 70s were significantly different at $\alpha < 0.01$. When compared to the Dixie Alley region, the influence of population density on tornado reporting does not seem to be quite as strong. While the decades of the 90s and 00s are still significant at the $\alpha < 0.05$ level, there is less confidence that tornado density is significantly different in counties of high vs. low population density in the state of Alabama when compared to Dixie Alley as a whole.

Table 4.8. Test of significance for county tornado densities (per 1000 $km^2$) between high and low population counties in Alabama

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 1.055 | 3.118 | 4.19 | ** |
| **80s** | 2.461 | 3.444 | 1.22 | |
| **90s** | 3.287 | 4.881 | 1.94 | * |
| **00s** | 6.144 | 8.299 | 1.90 | * |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

*Georgia*

Of the three states tested, the results for the state of Georgia were the most similar to the regional results for Dixie Alley. Each of the first three decades tested had mean tornado densities that were significantly different for high and low populated counties at

$\alpha < 0.01$. The last decade tested (2000s) did not have a significant difference in the mean tornado density for high and low population density counties. Although there was no significant difference, the mean tornado density for the high population density counties was still higher than the mean tornado density for the low population density counties. The reason that the last decade did not indicate a significant difference may be a result of the increased awareness of where these tornadoes are occurring due to the increase in meteorological technologies and education.

Table 4.9. Test of significance for county tornado densities (per 1000 $km^2$) between high and low population counties in Georgia.

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 1.998 | 4.305 | 4.04 | ** |
| **80s** | 1.717 | 3.509 | 3.31 | ** |
| **90s** | 2.425 | 4.08 | 2.69 | ** |
| **00s** | 3.523 | 4.216 | 0.81 | |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

*Mississippi*

Although the state of Mississippi has a higher mean tornado density for counties with high population density than counties with low population density, the level of significance is lower than any other state tested in Dixie Alley. There is still a significant difference at the $\alpha$<0.05 level during the 70s and 80s, but the 90s and 00s do not indicate a statistically significant difference in mean tornado density. One noticeable trend is the continual increase in tornado density that has occurred since 1970. In many of the study areas, tornado density did not continue to increase through the 90s to the 00s. However, in Mississippi, mean tornado density continued to increase from the 90s and into the 00s for both high and low population density counties. This trend may be an indication that tornadoes are still being under reported since meteorological phenomena would not exclusively lead to this dramatic increase. It also should be noted that this trend in tornado density growth directly parallels growth in population density.

Table 4.10. Test of significance for county tornado densities (per 1000 $km^2$) between high and low population counties in Mississippi.

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 1.974 | 3.491 | 1.95 | * |
| **80s** | 3.368 | 4.786 | 2.21 | * |
| **90s** | 4.676 | 6.209 | 1.54 | |
| **00s** | 7.262 | 9.136 | 1.35 | |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

*Oklahoma*

The state of Oklahoma also contains higher tornado densities for counties of high population density than for counties of low population density. However, only the 70s have a significant difference in tornado density between high and low population density counties at $\alpha<0.01$. While the 80s and 90s indicate a significant difference at $\alpha<0.05$, the 00s do not have a significant difference in mean tornado density between high and low population density counties. The trend of the 70s having a significance at $\alpha<0.01$ to the 00s having a significance at $\alpha<0.05$ is likely an indication that population, while likely influencing tornado reporting, is increasingly less influential over time. One noticeable difference in the results in Oklahoma is the decrease in mean population density that occurred from the 90s to the 00s. Both of the tested sub-regions have experienced an end to the steady increase of mean population density, but neither had a decrease like Oklahoma. One possible explanation for the mean tornado density decrease could be solely because of meteorological factors. The 1990s was a very active decade in terms of tornado frequency. The 1999 season was especially active. This particular year holds the record for most tornadoes reported (145) within the state. This record is mostly due to the large outbreak of tornadoes on May 3, 1999. This day alone had 60 reports in the state of Oklahoma.

Table 4.11. Test of significance for county tornado densities (per 1000 km$^2$) between high and low population counties in Oklahoma.

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 2.516 | 5.063 | 3.77 | ** |
| **80s** | 4.616 | 6.086 | 1.89 | * |
| **90s** | 7.584 | 9.779 | 1.83 | * |
| **00s** | 4.997 | 5.870 | 0.82 | |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

*Kansas*

Kansas has an overall increase in mean tornado density from the 70s to the 00s that is similar to the tornado density increase that was seen in the Tornado Alley region. However, the mean tornado densities of the high and low population density counties are not significantly different for three out of the four tested decades. The 80s is the only decade tested that contained a significant difference between the mean tornado density of low and high population density counties. The other decades are almost identical in terms of mean tornado density. In fact, the 70s and 00s have tornado densities that are slightly smaller for counties with high population density than for counties with low population density. This is the only state in the study area with this scenario. With the exception of the 80s decade, it appears that Kansas tornado reporting is influenced less by population than any other state or region tested.

Table 4.12. Test of significance for county tornado densities (per 1000 km$^2$) between high and low population counties in Kansas.

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 2.444 | 2.237 | 0.49 | |
| **80s** | 2.894 | 5.010 | 3.17 | ** |
| **90s** | 7.839 | 8.288 | 0.30 | |
| **00s** | 8.511 | 8.119 | 0.25 | |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

*Nebraska*

Nebraska has a general increase in the mean tornado density from the 70s to the 00s, but there is some slight fluctuation. For example, the 70s has a slightly higher mean tornado density than the 80s and the 90s has a slightly higher mean tornado density than the 00s. The mean tornado density for the high population density counties is higher than the mean tornado density for the low population density counties for each tested decade. This indicates that tornado reporting is likely influenced by population density. Further evidence that a strong relationship may exist between tornado reporting and population in Nebraska is in the T-Values and corresponding significance that was found for each decade. All decades show a significant difference in tornado density between high and low population density counties of at least α<0.05. The 70s and 90s were significantly different at α<0.01.

Table 4.13. Test of significance for county tornado densities (per 1000 $km^2$) between high and low population counties in Nebraska.

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 3.572 | 5.624 | 2.70 | ** |
| **80s** | 2.953 | 5.187 | 2.21 | * |
| **90s** | 6.205 | 10.100 | 3.12 | ** |
| **00s** | 5.190 | 7.993 | 2.06 | * |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

*South Dakota*

South Dakota also has a general increase in tornado density throughout the study period. With the exception of the 80s, each decade had a significant difference in mean tornado density between the low population density and high population density counties. This difference was significant at α<0.01 in each decade except the 80s (α<0.05). In each case, the tornado density of the high population density counties was greater than the tornado density of the low population density counties. These findings show that like most of the other tested regions, tornado reporting in South Dakota is strongly influenced by population.

Table 4.14. Test of significance for county tornado densities (per 1000 $km^2$) between high and low population counties in South Dakota.

| Decade | Tornado Density For Low Population | Tornado Density For High Population | T-Value | Significance |
|---|---|---|---|---|
| **70s** | 2.197 | 5.425 | 5.85 | ** |
| **80s** | 2.714 | 4.917 | 2.14 | * |
| **90s** | 2.911 | 5.692 | 4.04 | ** |
| **00s** | 1.773 | 10.534 | 3.15 | ** |

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

The two-sample difference of mean tests that were conducted for the study areas revealed that in each case there was at least some significant difference in the mean tornado density of low and high population density counties. With the exception of only two decades in the state of Kansas, every decade tested for every state and region contained a higher mean tornado density for high population density counties than for low population density counties. This is very important as it indicates a directional relationship between tornado density and population density (i.e. as population increases, tornado reports increase). Also of note is the trend that occurs in each region in regards to the significant differences that exists between the mean tornado densities of high and low population density counties. The Continental U.S. has a significant difference for every decade tested. The T-values also indicate that the greatest difference occurs in the

70s and these differences gradually decrease during each studied decadal period. When areas of highest tornado frequency were studied on a smaller scale, similar results were found. The sub regions and states studied indicate the greatest difference of means in the decade of the 1970s and their lowest in the 2000s. Although there were a few exceptions, there are two general conclusions that can be drawn from these tests. 1) Higher population density results in higher tornado reporting; and 2) the influence that population has on tornado reporting, while still significant, has decreased in recent years.

**Discriminant Analysis for Education**

Considering the strong relationship that was found to exist between the number of tornadoes reported and population density, it was deemed necessary to test for a relationship with another possible variable. If the distribution of population throughout an area has an effect on a population's reporting frequency, it would be interesting to know if the education level of that population has an effect on the frequency of tornadoes reported.

In order to test for a possible relationship between education level and tornado reporting, discriminant analysis was conducted using three unique education levels. The number of people in each county was assigned an education level based upon if they had no high school education, a high school diploma, or at least two years of college. The analysis was used to find if education level is a significant factor in predicting if a particular region will report a high or low number of tornadoes. This was calculated separately for the Great Plains and Dixie Alley Region. The results indicate that the education level of a county could accurately be linked to the tornado density of that county only 50-54% of the time. These results are similar to what might be expected from a coin flip. Therefore, it can be concluded that education level (as defined in this study) should not be used as a predictor for the number of tornadoes reported in that county.

The results attained from this analysis indicate that general education level is not a good indication of one's ability or desire to report a tornado. However, the level of "weather education" is likely a better indicator of determining the frequency and accuracy in which the public reports tornadoes. With the increase in media coverage of severe weather outbreaks and more storm spotting programs, weather education has likely had a countrywide increase in recent years. With this increase in weather knowledge, tornadoes will likely become more accurately identified and spotted by the public in the future.

# CHAPTER V

## SUMMARY AND CONCLUSIONS

Having an accurate spatial representation of tornadoes is crucial for the advancement of tornado research. Knowledge of when and where tornadoes occur is critical for the researcher as it facilitates an understanding of the environmental conditions necessary for tornado development. Because of the nature of weak tornadoes occurring in unpopulated areas, it is nearly impossible to report every tornado that occurs or has occurred in the past. This study has shown that the relationship between population and tornado reporting is not linear and no bias correction can be applied to the tornado database. Nevertheless, recognition of this relationship is important and opportunities to mitigate the problems using technology should be attempted.

Highway and city buffer analyses point to strong countrywide population biases. The tornado-population relationship is higher for population related to cities than interstate highways. This is likely a result of more observers being present in a city (regardless of time of day) than what would exist along an interstate highway. It is also likely more difficult to report a tornado from a highway in the earlier years of this study period because of the limited technology (i.e. cellular phones). Regardless of the city or interstate analysis, the population influence West of Denver appears greater than in the region East of Denver. This is likely due to the lower population density that exists in many areas of the Western United States. Many weak tornadoes are likely not reported in these areas of low population simply due to a lack of observation. Therefore, any increase in observers related to cities or highways allows for a much higher rate of reporting.

The two sample T-Tests that were conducted indicate that the frequency of tornado reporting has paralleled the increase in population since the 1970s. Every tested decade in the Continental United States found that tornado densities were significantly different for high and low population density counties. When restricted to the regional levels of Dixie Alley and Tornado Alley, every tested decade with the exception of the 2000s contains significant differences related to tornado density between high and low population density counties. Although the T-values indicate that the difference between tornado density for high and low population density counties is less for these two regions than what was found nationally, a strong population influence on tornado reporting is still apparent. These tests also give an indication of the state-level relationships that exists between population density and tornado density within the regions of Dixie Alley and Tornado Alley. Although some state-to-state fluctuation exists, there is generally less influence related to population on tornado reporting in recent years. The variation that exists from state to state within these regions is likely a result of meteorological variables not measured in this study. For example, an increase in actual tornado occurrence such as what occurred in Oklahoma in the 90s may mask the population influence on tornado observation at the state scale. Therefore, it is more helpful to identify population and tornado relationships on a regional level.

This study has shown that population is a significant factor in the frequency in which tornadoes are reported throughout the Continental United States. Although a correction factor cannot be applied to the tornado database, it is important to understand that population impacts (in some areas strongly impacts) the reporting of weak tornadoes.

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APPENDIX

AN ANALYSIS OF THE RELATIONSHIP BETWEEN

POPULATION AND THE REPORTED

NUMBER OF TORNADOES

# APPENDIX

Although previous research (Frisbie 2006 and Anderson et al. 2005) points to population not having a significant influence on the reporting of strong tornadoes, informal conversations with SPC (Severe Storm Prediction) Meteorologists led me to investigate if any relationships between strong tornadoes and population do exist. In order to test for relationships between high population and strong tornado reporting, the same city and highway proximity methods previously used for weak tornadoes were used for strong tornadoes. However, because of the small number of strong tornadoes that occur west of Denver, CO, the area of study for strong tornadoes was restricted to the Eastern U.S. The strong tornadoes (>F1) that were used in this study were also separated into subgroups in order to see if any trend existed for tornadoes of greater intensity. Three subgroups were used for the highway statistics. They were F2-F5, F3-F5, and F4-F5. The city proximity stats used only two subgroups because of the small number of F4 and F5 tornadoes that have been reported within close proximity to major cities since 1970.

**Highway Buffers**

The results in Table A.1 show that there are a higher percentage of tornadoes within the tested highway buffers in the Eastern U.S. than would generally be expected considering the amount of land area it contains. When compared to the tornado/land ratios that were calculated for weak tornadoes in the Eastern U.S., the difference in tornado percentage vs. land percentage is very similar. The majority of the tested proximity distances produced a result of approximately 1.5 times more tornadoes than expected from a random distribution. The largest ratio of strong tornadoes vs. land percentage was calculated for tornadoes of F4 or F5 ranking within 1 km of an interstate highway. This calculated 2.23:1 ratio is a bit higher than what was found for weak tornadoes. However, the limited number of strong tornadoes that have occurred within 1 km of an interstate highway during this study period leads to lower confidence and does not allow for any assumptions to be made about this particular finding.

Table A.1. Highway proximity relationships with strong tornadoes in the Eastern United States.

| | **F2-F5 Tornadoes** | | | **F3-F5 Tornadoes** | | | **F4-F5 Tornadoes** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Proximity Distance** | Land | Tornado | Ratio | Land | Tornado | Ratio | Land | Tornado | Ratio |
| **1.0 km** | 2.2% | 3.5% | 1.59:1 | 2.2% | 3.3% | 1.50:1 | 2.2% | 4.9% | 2.23:1 |
| **2.5 km** | 5.4% | 8.5% | 1.57:1 | 5.4% | 8.0% | 1.48:1 | 5.4% | 8.5% | 1.57:1 |
| **5.0 km** | 10.8% | 15.8% | 1.46:1 | 10.8% | 15.4% | 1.43:1 | 10.8% | 17.6% | 1.63:1 |

**City Proximity**

The analysis conducted for strong tornadoes within specified distances around cities in the Eastern United States produced results that again point to population affecting the number of tornadoes reported. Table A.2 shows a higher percentage of strong (F2-F5) tornadoes than expected for each of the tested proximity distances and population sizes. When compared to the weaker tornadoes, a noteworthy difference cannot be found. The difference in tornado percentage versus land percentage experiences a very similar increase as the proximity distance is decreased and the population parameter is increased.

Table A.3 shows the results for strong tornadoes restricted to F3 ranking or greater. The findings show that strong tornadoes are again reported at a higher rate than expected in the Eastern U.S. However, when compared to weak tornadoes, a noteworthy difference cannot be found in the percentage of tornadoes reported compared with the percentage of land that the studied area encompasses.

Table A.2. City proximity relationships with strong tornadoes (>F1) in the Eastern United States.

| | **Population 25,000** | | | **Population 50,000** | | | **Population 100,000** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Proximity Distance** | Land | Tornado | Ratio | Land | Tornado | Ratio | Land | Tornado | Ratio |
| **2.5 km** | 0.37% | 1.64% | 4.43:1 | 0.15% | 0.84% | 5.60:1 | 0.05% | 0.41% | 8.20:1 |
| **5.0 km** | 1.47% | 4.01% | 2.73:1 | 0.61% | 2.03% | 3.33:1 | 0.21% | 0.89% | 4.24:1 |
| **10.0 km** | 5.92% | 8.40% | 1.42:1 | 2.20% | 4.64% | 2.11:1 | 0.85% | 2.38% | 2.80:1 |

Table A.3. City proximity relationships with strong tornadoes (>F2) in the Eastern United States.

| | **Population 25,000** | | | **Population 50,000** | | | **Population 100,000** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Proximity Distance** | Land | Tornado | Ratio | Land | Tornado | Ratio | Land | Tornado | Ratio |
| **2.5 km** | 0.37% | 1.35% | 3.65:1 | 0.15% | 0.78% | 5.20:1 | 0.05% | 0.39% | 7.80:1 |
| **5.0 km** | 1.47% | 3.60% | 2.45:1 | 0.61% | 1.86% | 3.05:1 | 0.21% | 1.03% | 4.90:1 |
| **10.0 km** | 5.92% | 8.49% | 1.43:1 | 2.20% | 4.69% | 2.13:1 | 0.85% | 2.64% | 3.11:1 |

Although conventional wisdom would lead to the assumption that population would more greatly influence the reporting of weak tornadoes, these findings show that the relationship between population and strong tornadoes is similar to that which was found for weak tornadoes. The shorter storm track and weaker damage path of weak tornadoes would seem to suggest that they would be more difficult to identify and report. However, there may be additional factors involved that could influence the reporting of strong tornadoes. Even though they are much easier to identify and report because of their larger damage path, the method of ranking could play a role in this apparent population bias. The Fujita Scale ranks tornadoes based on the amount of damage they produce. Therefore, in order for a tornado to receive a high ranking, it must cause significant damage to some kind of structure. Since population is correlated with a high number of structures, it would be easier for a tornado to receive a high ranking in an area of high population than in an area of low population.

Although the results from the buffer analysis suggest that the influence of population on strong tornadoes is similar to weak tornadoes, more thorough research needs to be conducted. While this analysis points to a substantial relationship, there is conflicting research suggesting that population does not influence the reporting of strong tornadoes (Frisbie 2006 and Anderson et al. 2005). More work in the area of strong tornadoes and population needs to be undertaken.